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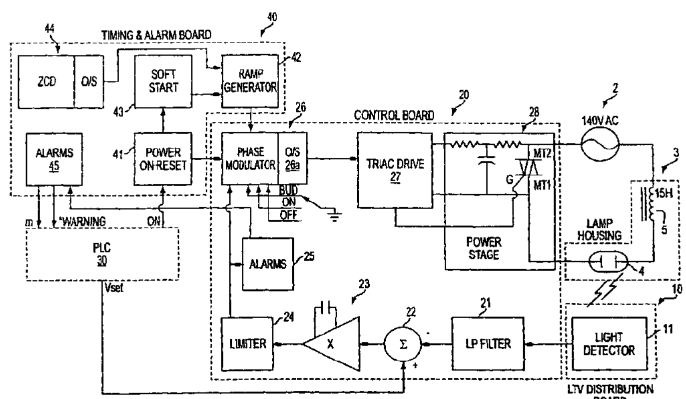
(54) Title: METHOD OF AND SYSTEM FOR CONTROLLED CURING OF POLYMERS USED IN CONTACT LENS MANUFACTURE



(57) Abstract: A polymer curing system in which exposure of a polymer precursor mixture to curing radiation includes actively controlling curing radiation intensity. This results in far more successful manufacture and generally higher and more consistent quality polymer products. A closed loop control scheme regulates the lamp intensity of a PL-S lamp at one wavelength by sensing light output by the lamp at another wavelength and controlling lamp power through AC phase modulation. Preferably, the scheme regulates UV intensity in response to sensed visible light emitted by the lamp. This scheme provides compensation for lamp and ballast manufacturing variability, temperature effects, line voltage fluctuations, and lamp aging. The controller can set the intensity of a number of banks of lamps and any lamp can be assigned to any bank. Once set, the variability of UV light intensity, as measured substantially at the lamp, is controlled to within $\pm 40\ \mu W/cm^2$ and the need to measure the intensity of the process occurs only at regular PMS intervals. The controller monitors and reports lamp failure and near end of lamp life. Soft start circuitry eliminates on/off cycling stresses, and cycling lamps on only when needed yields increased lamp useful life. Further, the system reduces typically long warm up periods experienced in the prior art to less than a minute and even to just a few seconds.

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METHOD OF AND SYSTEM FOR CONTROLLED CURING OF POLYMERS USED IN CONTACT LENS MANUFACTURE

Related Patent Application

This application is related to U.S. Patent Application Number 09/___,____, filed on __ _____ _____, entitled "Method of and System for Closed Loop Control of Fluorescent Lamps."

Technical Field

The invention concerns a method of curing of contact lenses in a mold by closed loop control of the variation and/or change in intensity over time of the actinic radiation employed to cure the lens, thereby forming a lens article having preselected properties.

Background of the Invention

Manufacturers of contact lenses use lathing, molding, or spin-casting to create their lenses. My invention particularly deals with molding, in which two mold surfaces define the surfaces of the lenses, but could conceivably be applied to spin-casting. Typically, molding involves mixing monomer, comonomer, and/or macromer/prepolymer components with a photoinitiator, placing the mixture in a mold, and exposing the mixture to light of the particular wavelength to which the photoinitiator responds. This mixture can also be called a lens-material precursor mixture. One class of commonly used photoinitiators is sensitive to ultraviolet (UV) light. Some manufacturers use a main table in an index casting machine that includes multiple clamping stations. Molds enter the casting machine at an entry position and move from indexed position to indexed position, remaining at each index position for a particular amount of time, until the molds reach an exit position. Once the molds leave the casting machine, some manufacturers send them to a "post cure" table where they expose the molds to additional light, completing the curing of the mixture. Then, the manufacturer adds water to the cured lens to form a hydrogel.

Contact lens manufacturers typically consider the curing to be essentially a matter of total dosage of actinic radiation. In some cases, manufacturers attempt to cure with a large dose in order to minimize the time needed to cure the lens. In essence, contact lens manufacturers do not consider the active control of the change in the intensity of actinic radiation over time as a factor in obtaining preselected properties of a contact lens.

Contact lens manufacture suffers from a relative high failure rate so that many finished lenses must be thrown away. Maintaining the dimensional properties of the lens within required tolerance levels is difficult. For example, the diameter of lenses manufactured with current techniques can vary as much as 74μm, or nearly 20% of the specified tolerances, which are typically on the order of 100 μm. Attempts have been made to improve dimensional consistency, for example, using different mold materials or mold designs. Modulus of contact lens materials is an important factor in lens comfort, and attempts have been made to develop lens-material precursor mixtures or formulations that provide the desired modulus in the molded product. However, some formulations that have some desired properties such as high Dk do not produce the required modulus in the finished lens. New formulations are therefore continuously developed and tested in order to find the right physical or clinical properties. Moreover, some contact lenses require high manufacturing costs because of the difficulty of extracting residual (incompletely cured) components from the lens after it is cured.

Thus, the design of the molds, the composition of the monomer mixes, and the cure process determine contact lens and material bulk properties, and variation in any of these will result in variation in the product. The effect of light intensity in UV cure, for example, has been overlooked as a control to achieve an optimum and uniform product quality.

There is a need for methods of manufacturing lenses that have the required dimensional, physical, and chemical properties and a need for controlling those properties during manufacture.

Summary of the Invention

To my surprise, and to the surprise of my colleagues, I found that several important contact lens properties vary significantly depending on variations in the intensity of cure radiation over time. Depending on the particular conditions, I

have observed that properties of contact lenses such as diameter or sag (dimension properties), percentage of water content or modulus of elasticity (physical properties), and residual component extractable levels (chemical properties) can vary widely from lens to lens in part from fluctuations in lamp intensity fluctuations on the main and/or post cure tables. Furthermore, it has been found that the dimensional, physical, or chemical properties of contact lenses can be obtained by actively controlling the intensity of the light used to cure the lens over time.

My invention dramatically improves consistency of quality in hydrogel curing, specifically in contact lens manufacture. Rather than simply turning on curing lamps and leaving them to run at whatever intensity the line voltage and current can generate, I control the intensity by actively controlling power applied to the lamp or other light source. I have found that maintaining the lamps at constant intensity yields more consistent properties in the end products. In contact lens manufacture specifically, diameter and sag are far more consistent, and residual content of components is greatly reduced.

In one embodiment of the invention, I achieve this control of the source of actinic radiation by using a closed loop control system, for example, by sensing lamp intensity as a basis of controlling lamp power. Once the intensity of light is set over time, the variability of light intensity at the lamp can be controlled within ± 40 μW/cm^2 and the need to measure the intensity of the process occurs only at regular PMS intervals. The controller can also monitor and report lamp failure and near end of lamp life.

In another embodiment of the invention, I achieve preselected properties of a lens by ramping up the intensity of light over a given period of time. Other light-intensity profiles can be determined, depending on a given lens formulation (lens-material precursor mixture) and details of manufacture (for example, whether using a post cure heat).

The system is particularly useful in UV curing of polymers used in, for example, contact lens manufacture using index casting machines. My invention can yield more consistent quality of such products since it can maintain UV intensity at a given level regardless of lamp aging, lamp and ballast manufacturing variability, line voltage fluctuations, and temperature effects. My invention can also yield preselected properties of lenses to the extent they

depend on the path of cure (the rate of dosage change, i.e., the variation of the light intensity over time).

Description of the Drawings

FIG. 1 is a chart showing the emission spectrum of a typical light source for curing lenses, in this case a fluorescent lamp.

FIG. 2 is a chart showing output intensity of a fluorescent lamp as the number of hours of on time for the lamp increases.

FIG. 3 is a chart of the intensity of a fluorescent lamp as a function of temperature.

FIG. 4 is a chart of lamp intensity as a function of line voltage.

FIG. 5 is a chart showing lamp intensity variation in a typical fluorescent lamp in a typical usage situation after the lamp has been on and warmed up for some time.

FIG. 6 is a chart showing the behavior of a typical fluorescent lamp as it starts up.

FIG. 7A is a schematic block diagram of an exemplary embodiment of my curing system using an index casting machine as the curing machine.

FIG. 7B is a schematic block diagram of a preferred controller of the invention.

FIG. 8 is a schematic circuit diagram of a preferred zero crossing circuit of the invention.

FIG. 9 is a schematic diagram of a preferred ramp generator of the invention.

FIG. 10 is a schematic diagram of a preferred soft start circuit of the invention.

FIG. 11 is a schematic diagram of a preferred power on reset circuit of the invention.

FIG. 12 is a chart showing the typical spectral response of a preferred photodiode of the invention.

FIG. 13 is a schematic diagram of a preferred filter/error amplifier circuit of the invention.

FIG. 14 is a schematic diagram of a preferred limiter circuit of the invention.

FIG. 15 is a schematic diagram of a preferred phase modulator circuit of the invention.

FIG. 16 is a schematic diagram of a preferred power stage circuit of the invention.

FIG. 17 is a schematic diagram of a preferred alarm discrete circuit of the invention.

FIG. 18 is a schematic diagram of a preferred controller alarm circuit of the invention.

FIG. 19 is a chart showing the variation of the primary AC voltage, ramp voltage, triac trigger voltage, sensed light signal voltage, and filtered sensed light signal voltage produced by respective preferred circuits of the controller of FIG. 7A over time, thus illustrating the relative timings of the variations of the voltages.

Description of the Invention

As mentioned above, the invention relates to the curing of a lens precursor material during the production of contact lenses and, more specifically, relates to curing systems in which radiation intensity is controlled. The lens-material precursor mixture used in photoinitiated contact lens manufacture typically includes monomers and/or comonomers that result in a crosslinked polymer. For example, the lenses can be made from hydrophilic polymers, including polyhydroxyethyl methacrylate and polyvinyl pyrrolidinone based systems. Generally, the present invention is applicable to contact lenses of the gel, hydrogel or soft type, whether made from the more traditional copolymers such as 2-hydroxyethyene methacrylate (HEMA) or from the newer silicon-containing hydrogel materials.

As mentioned above, preselected properties of the lenses can be obtained by applying my inventive system of actively controlling UV intensity or other actinic radiation. For example, I observed a nearly negligible variation in diameter and drastic reductions in extractable levels of lens-material components (whose presence in the finished lenses is undesirable) by controlling the light intensity over time.

According to a preferred embodiment of the invention, as seen in FIG. 7A, a system 6 modifies existing curing systems by adding a light sensor 11 for each lamp 3 or bank of lamps in a curing machine 7, such as an index casting machine. An index casting machine can include a main table 7a with clamping positions 7b onto which molds 7c containing polymer precursor mixture to be cured can be placed and removed through entry and exit positions 6a, 6b. A post cure table 8 can also be included. The light sensor 11 produces a voltage proportional to light incident on the sensor. The system 6 modifies and monitors this voltage to produce a control signal for the power stage 28 (see FIG. 7B) of the curing machine so that the lamps 3 produce a desired intensity of the curing radiation. Details of an exemplary embodiment of my inventive system follow.

A Source of Actinic Radiation

A variety of sources for cure radiation can be employed in contact lens manufacture to cure hydrogel materials, including but not limited to fluorescent lamps, high-pressure or low-pressure mercury vapor lamps, excimer lasers, and the like. An economical choice for a UV lamp is the low-pressure, mercury fluorescent lamp known as the PL-S 9W/10. The PL-S style lamp is a two pin, twin tube, compact fluorescent lamp with an integral starter and produces the bulk of its light between 350-800 nm. FIG. 1 shows the typical emission spectrum of such a PL-S lamp. A typical lamp and ballast configuration running continuously under nominal conditions of line and temperature can produce intensity levels, measured at or near the lamp, as high as 12 mW/cm^2 during the first few hours of life to as low as 3 mW/cm^2 after 2000 hours of continuous use. The degradation in intensity level results from uncontrolled on/off cycling of the lamp, which can cause degradation of the phosphor coating of the lamp from sputtering. This 4 to 1 reduction in lamp output over the life of the lamp is typical even though the actual intensity levels depend heavily on the measurement system and the conditions under which the measurements were taken. FIG. 2 shows the relationship of intensity as a function power on hours (POH) for a

typical lamp used on a casting machine measured using a UV gauge. This intensity is the combination of gauge response and lamp spectral emission and represents the total energy in the emitted spectrum. The intensity decreases in an exponential-like fashion from 5500 $\mu W/cm^2$ at day 10 to 3500 $\mu W/cm^2$ at day 80 and may be due to tube glass solarization, phosphor degradation, or impurities in the gas. In this assessment, POH only accumulate when the lamp is on, as the name suggests.

The intensity of the lamp is also affected by temperature as shown in FIG. 3. At low temperatures, the lamp's output is dominated by the quantum conversion efficiency of the lamp gas. This phenomenon is a function of current density of the discharge column, which depends on the vapor pressure of the gas and current flowing through the lamp. For fixed lamp current, the current density increases as temperature increases due to increased vapor pressure. At higher temperatures, the phosphor coating's conversion efficiency decreases as temperature increases and becomes the factor dominating the output.

Increasing the current to the lamp increases the power to the lamp and also increases the temperature. The resulting intensity will usually be higher. However, there is a point of diminishing returns as a result of the relationships explained above. The increase in temperature will certainly decrease the lamp life; and, for the PL-S style lamp, the filaments will burn up if the current is too much above the rated level.

The current through the lamp and the voltage across the lamp are typically in phase, and the voltage across the lamp is generally almost constant over a wide range of lamp current. Since the lamp current is proportional to the voltage across the ballast and inversely proportional to the inductance of the ballast, increasing the line voltage will increase the voltage across the ballast and cause a proportional increase in lamp current. FIG. 4 shows the relationship between line input voltage and lamp intensity. The first part of the plot shows the lamp's intensity at 120 VAC, the second at 100 VAC, and the third at 140 VAC. The voltage affects intensity at about 100 $\mu W/cm^2/VRMS$.

Additionally, the inherent variability in the ballast inductance accounts for as much as 1000 $\mu W/cm^2$ as a result of the relationships discussed above.

Actinic radiation in the UV and/or visible light spectrum is preferred for curing contact lenses. Intensity is affected by the location of the lamp relative to

its reflector, the shape of the reflector, the surface condition of the reflector, and the interaction of the light spectral response to any transmission medium including, in the case of contact lens manufacture with index casting machines, mold material and casting chamber covers.

Any spatial differences in the orientation of the mold relative to the source between casting positions will add to the variability of intensity at the mold. For instance, the epsilon or delta series indexing machines use three clamp positions and the Quattro series use four. The spatial response to a single light source is different across the clamp positions and is estimated at 600 $\mu W/cm^2$ for the former and 1000 $\mu W/cm^2$ for the latter casting machine series. Additionally, light from each lamp adjacent to a particular clamp position aids the lamp directly above the clamp position as do the lamps adjacent to these lamps, etc.

Irregularities in the casting machine top cover caused by gaskets, hardware, and top cover material overlaps cause shadows to appear that can drop the intensity by 3000 $\mu W/cm^2$.

An ideal scheme to control intensity would incorporate power and temperature control. In a preferred embodiment of UV control in response to sensed visible light, the system is capable of regulating UV light intensity to within 40 $\mu W/cm^2$ of the set point for a given temperature, intensity again being measured at or near the lamp. One solution for the control regulates temperature; another neutralizes the effect of temperature. FIG. 5 shows a typical intensity plot over time for both open loop and closed loop operation.

An added benefit to intensity control is the elimination of long warm-up periods. Since the lamps reach minimum UV intensities within seconds after turn on and reach a stable operating temperature range within ten minutes after that, the control loop can begin to regulate the intensity immediately after the set point has been exceeded. This will mean that the lamps can be turned off when not in use; their usable life can thus be extended. FIG. 6 shows a plot of UV intensity vs. time at start up for a PL-S lamp with and without closed loop control. The plot shows that at 5 minutes the open loop lamp intensity is still climbing to the final value whereas the closed loop lamp's intensity stabilized within about 15 seconds.

FIG. 7B shows a block diagram of an exemplary embodiment of a closed loop system 1 for use in one embodiment of the present invention. The intensity

of light emitted by the lamp 3 is controlled when driven by an AC power source 2 and the controller 1. To understand this control mechanism, I first assume that the lamp 3 operates at a stable intensity. If a disturbance comes along, such as an increase in line voltage, the power delivered to the lamp 3 increases and the intensity increases as well. Likewise, a decrease in line voltage decreases power to the lamp and lamp 3 intensity. Increased light incident on the photosensor increases its output voltage.

The exemplary controller of FIG. 7B includes the photosensor, such as the light detector 11, preferably disposed on an LTV (Light to Voltage) distribution board 10 and connected to a filter 21 (such as a low pass filter) on a control board 20 that also carries a comparator 22 (such as a summation circuit), an error amplifier 23, a limiter circuit 24, an alarm circuit 25, a phase modulator 26, a triac drive 27, and a power stage 28. The filter 21 is connected to the comparator 22, which in turn is connected to the error amplifier 23, which sends its output to the limiter circuit 24. The limiter 24 sends its output to the phase modulator 26, which controls the triac drive 27 via a one-shot 26a; and the triac drive 26 controls the power stage 28.

The phase modulator 26 of the exemplary controller 1 in FIG. 7B is also connected to a control device 30, such as a programmable logic controller (PLC), and to components on a timing and alarm board 40, including a power on reset circuit 41, which is also connected to the control device 30, and a ramp generator 42, which is connected to a soft start circuit 43 and a zero crossing detector 44. The alarm circuit 25 of the control board 20 is connected to another alarm circuit 45 on the timing and alarm board 40, which is also connected to the control device 30.

The output voltage of the photosensor 11 is filtered by a filter 21, such as a low pass filter, and scaled to produce a DC voltage inversely proportional to the incident light intensity. As an example, when incident light intensity increases, the filtered, scaled DC voltage level decreases. This voltage is compared to a reference (set point) voltage at the comparator 22, and the difference is amplified by the error amplifier 23. Under steady state conditions, these voltages would be the same and the output from the error amplifier 23 would be some constant value. However, due to the disturbance of increased incident intensity, an unbalanced condition exists and the output voltage from the error amplifier 23 increases.

If the unbalance is too great, the limiter circuit 24 will limit this voltage, but if not, the limiter circuit 24 has no effect on the control and the signal passes through undisturbed. The error amplifier voltage is applied to the phase modulator 26 and increases the delay in triggering the triac drive 27 and power stage 28. This delay decreases the power supplied to the load, which decreases the lamp's intensity proportionally. This decrease in power produces the correct adjustment through careful selection of gain and dynamic compensation of the error amplifier 23. If the disturbance is a decrease in line voltage, the description of the process is the same except the word "decrease" replaces the word "increase."

Circuit Details

The following sections describe with some more detail the circuits used in the block diagram shown in FIG. 7B.

Zero Crossing Detector

Preferably, a group of circuits produce a logic level low pulse of about 100 μsec every time the AC primary voltage crosses zero. This pulse provides the timing to terminate and initiate a new voltage ramp cycle and controls the firing phase angle of the power stage. FIG. 8 shows the schematic of this circuit, the zero crossing detector 44. A sample of the sinusoidal AC primary voltage from the AC power source 2 is sensed across a transformer T1 and squared up by a clamped, analog voltage comparator 441, preferably including a LM339 unit, that produces a symmetric square wave. Resistors R5 and R6 provide a small amount of hysteresis to suppress spurious oscillations near the zero crossing point and resistors R4/R5 and resistors R3/R2 bias the signal into the range of the single supply voltage comparator. This waveform is applied to a "one-shot" multivibrator 441 triggered on the rising edge of the square wave and also to another one-shot triggered 442 on the falling edge of the square wave. Preferably, both one-shots are 74LS123 units. Resistor R7 provides a TTL logic compatible high level to the preferred 74LS123 trigger inputs and resistor R8/capacitor C2 and resistor R9/capacitor C3 determine the pulse widths at the outputs. I prefer to use 5.1KΩ resistors at R1, R2, and R7, 100KΩ resistors at R3 and R4, a 10KΩ resistor at R5, a 1MΩ resistor at R6, and 2.7KΩ resistors at R8 and R9. I also prefer to use 0.01μF capacitors at C2 and C3.

Ramp Generator

The ramp generator shown in FIG. 9 preferably includes an open collector, logic compatible comparator 421, and a constant current source U4. The outputs of the zero crossing detector's one-shots are "wire-ANDed" together at the input 422 to the comparator 421 to produce a 100 μsec pulse at two times the AC primary frequency. While these specific values for the pulse duration and frequency are preferred, other durations and frequencies can be used depending on the particular needs of the user. A precision constant current source programmed by a potentiometer preferably charges a capacitor C4 creating a linearly rising ramp. The comparator terminates the ramp cycle by applying the short across the timing capacitor. The charging rate and the time between reset pulses determines the maximum voltage the ramp attains; I prefer to set the voltage to about 7V.

The comparator is preferably made TTL logic compatible by setting the logic high level to .45V via the voltage divider R13/R14. The one-shot pulses are summed using resistor R10, resistor R11, and resistor R12 such that any one low logic level is guaranteed to produce less than the .45V at the positive input and two logic level highs are required to produce a voltage greater than the .45V. When the summed voltages are less than .45V, the comparator applies ground to its output discharging capacitor C4.

Resistor R15 is used to program the constant current source U4 and charges capacitor C4 at a constant rate. Since the voltage on a capacitor is equal to the product of the capacitor current times the time the current flows divided by the capacitance, a constant charging current will produce a linear voltage ramp. The open collector transistor at the output of the comparator discharges the timing capacitor every time a one-shot triggers, which resets the capacitor voltage to zero and begins a new cycle once the short is removed.

I prefer to use 10KΩ resistors at R10, R11, and R13; 1KΩ resistors at R12 and R14; and a variable resistor with a maximum resistance of 20KΩ at R15. I prefer to use a 0.01μF capacitor at C4, a LM339 comparator, and a LM334 type constant current source at U4.

Soft Start

Maximum utilization of lamp life is achieved by turning the lamp 3 off when not needed. However, lamp on/off cycles thermally stress the lamp filaments, causing burnout and vaporization of filament material, which contaminates the

lamp gas. The impurities in the gas cause a spectral shift and a degradation of lamp intensity. I therefore prefer to include a soft start circuit 43 that applies a slowly increasing filament current at lamp turn on to substantially avoid thermal stresses and filament vaporization. Soft starting is available after every power on reset (*POR), which is explained below.

After a power on reset pulse, the ramp voltage amplitude is preferably reduced below the minimum clamped error signal of the control loops by diverting ramp charging current away from the ramp capacitor 431. Since the ramp voltage is less than the error signal, power stage trigger pulses are inhibited and the lamp 3 is turned off, as is discussed in the description of the phase modulator. A voltage controlled current sink 432 diverts the ramp capacitor charging current so that the final ramp voltage is allowed to increase with time. When the ramp voltage increases to greater than the clamped error signal, trigger pulses are again delivered to the power stage every half cycle of the AC line voltage. As the ramp voltage increases, the trigger delay decreases, which in turn increases the current delivered to the lamp filaments. The slowly increasing lamp current warms the filaments slowly and eliminates the cold start stresses.

FIG. 10 shows the implementation of this circuit. The current sink 432 includes op-amp U5, transistor Q5, and resistor R18. The large gain of op-amp U5 guarantees that the inverting and non-inverting terminals of the op amp are at the same potential. The non-inverting op amp configuration applies a voltage necessary at pin 1 to cause transistor Q5 to conduct and sink current such that the voltage drop across resistor R18 is equal to the voltage at the non-inverting input. The voltage at pin 3 is a linearly falling ramp that starts at ground and decreases to a predetermined voltage over a predetermined period. Preferably, the voltage drops to about -5 volts in about 3 seconds. This signal diverts the ramp capacitor's charging current from about 9 μA at start to zero current at the end of the time out. I prefer to use a 2N2222 transistor at Q5 and a 560KΩ resistor at R18.

Resistor R25 through resistor R27 and transistor Q3 form a 2.5 μA constant current source 433 that charges capacitor C9 forming a ramp generator 434. The ramp is linear from ground to about -4.3 volts where transistor Q3 saturates. After saturation, the cap continues to charge to -5 volts at an exponential rate. Reset of capacitor C9 is provided by the optocoupler U8 which is controlled by *POR. I prefer to use 3.9KΩ, 1.2KΩ, and 200KΩ resistors at

R25, R26, and R27, respectively; a 1μF capacitor at C9; a 2N2222 transistor at Q3; and a CNY 17-1 optocoupler at U8.

Power On Reset

Power on reset (*POR, the asterisk signifying active low) is provided after powering up of the system, particularly the timing and alarm board, to allow the power supply voltages time to stabilize and also to guarantee known start up conditions for all circuitry. *POR is also gated with the PLC "ON" signal and is used to provide lamp on/off control. In a system including a plurality of lamps or a plurality of banks of lamps, each with a respective intensity control system, a single power on reset can be used; and the *POR can be made available to each respective phase modulator in this case so that, when the power on reset is active, it turns each lamp off. *POR can also be applied to the soft start circuit.

FIG. 11 shows a preferred arrangement of the power on reset circuit 41. Constant current source U3 and resistor R17 provide a constant current of about 2.4 μA into capacitor C1, which produces a linear voltage ramp. This voltage is compared to the 4.3 V output of the voltage divider 411, including resistor R19 and resistor R20, by comparator U2. Until the ramp exceeds 4.3 volts, the voltage comparator's output is at ground, which removes base drive from transistor Q1, turning it off. With transistor Q1 off, base drive is available to transistor Q2, which turns it on pulling *POR to ground. After about 2 seconds, the timing capacitor's voltage rises to greater than 4.3V and the comparator's output switches to its logic level high pulled up by resistor R23. Transistor Q1 is biased on through resistor R23, which removes base drive from transistor Q2, turning it off. Resistors R21 and R22 provide hysteresis to eliminate oscillations near the comparator's switching point. Transistors Q1 and Q2, resistor R23, and resistor R24 provide increased current sinking capability for the load on *POR. I prefer to use 270KΩ, 1.5KΩ, 2.7KΩ, and 1MΩ resistors at R17, R19, R21, and R22, respectively, and 10KΩ resistors at R20, R23, and R24. I also prefer to use a LM339 unit at U2, a LM334 constant current source at U3, and 2N2222 transistors at Q1 and Q2.

PLC on/off control is accomplished by optocoupler U9, resistor R32, resistor R33, and transistor Q7. The PLC provides a 24 V logic discrete, which indicates a lamp on condition. This voltage biases the LED portion of the optocoupler U9 on through resistor R32. The transistor portion then conducts and removes base drive from transistor Q7, turning it off. This allows the

controller to turn lamps on under normal control. When the 24 V discrete is removed, the LED and transistor of U9 turn off and base drive is restored to transistor Q7, which turns on and sinks the base drive of transistor Q1, making *POR true as explained above. This action results in the lamps turning off. I prefer to use 2.2KΩ and 10KΩ resistors at R33 and R34, respectively; a CNY 17-1 optocoupler at U9; and a 2N2222 transistor at Q7.

Sensor

Light is preferably sensed using a Texas Instruments TSL252 light to voltage converter 11 operating on a 5 V DC supply. The preferred spectral response shown in FIG. 12 is from 300 nm to 1100 nm. The detector also has sufficient wavelength bandwidth to faithfully reproduce the 120 Hz light pulse signal from the lamp and is shown in FIG. 19. The sensor is coupled to the lamp by means of a fiber optic cable. Preferably, the detector includes a filter or other device with a 600 nm cutoff that effectively creates a 600 nm to 1100 nm spectral bandwidth system. The energy contained in the bandwidth is integrated by the TSL252 and delivered as a voltage waveform.

Filter/Scaler

The output of the light sensor 10 is preferably scaled and filtered to provide a low ripple DC voltage of 0-5 VDC over the range of programmable lamp intensities. FIG. 13 shows a preferred exemplary arrangement of the filter 21 and error amplifier circuit 23, which also preferably includes the summation circuit 22. The scaling can be adjustable and can be used for calibrating the controller to match the PLC control voltage range. Minimum lamp intensity is attained at 5 VDC, and maximum lamp intensity is attained at 0 VDC. Capacitor C8 provides filtering and, with resistor R101, sets a pole at 10 Hz. Resistors R102 and R103 provide offset adjustment, and resistors R104 and R101 provide span adjustment. FIG. 19 shows the effect of the filter 21 for a typical TSL output.

Error Amplifier

A lossy integrating error amplifier is provided to compensate the control loop feedback and provide for stable operation. The amplifier operates in a differential mode with the conditioned intensity voltage and the set point control voltage as inputs. The loop gain is set by the feedback capacitor C7 and resistor R100 with a pole at about 3Hz. Bandwidth of the loop is determined by the

filtering stage preceding the error amplifier and the feed back pole. The output of the error amplifier is a DC control voltage used to modulate the firing angle of the power stage. FIG. 19 shows the timing for these waveforms. I prefer to use a 100KΩ resistor at R100, a 47KΩ resistor at R101, 10KΩ resistors at R102 and R103 (R103 being variable up to this value), and a variable resistor with a maximum resistance of 50KΩ at R104. I also prefer to use LM324 op-amps and capacitors of 0.54μF and 0.33μF at C7 and C8, respectively.

Limiter

The phase modulation control voltage must be limited to an upper and lower level to guarantee stable operation due to the inductive nature of the load and the lower permissible operating temperature of the lamp 3. This is accomplished by the precision clamping circuit with independently adjustable upper and lower limits included in the preferred limiter circuit 24 shown in FIG. 14. The phase modulation control voltage is unaffected by this circuit as long as its voltage remains between the limits of V_{min} and V_{max}. The lower limit establishes the maximum intensity (minimum phase delay) that the lamp can produce, and the upper limit establishes the minimum intensity (maximum phase delay) that the lamp can produce. Any phase delay less than the minimum phase determined by the power factor of the load will result in an additional 180° of phase in the control loop and will cause the controller to become unstable. This instability will cause the lamp to cycle on and off and will eventually destroy the lamp. Any phase delay greater than the maximum will cause the lamp to cool too much, resulting again in on and off cycling and eventual destruction of the lamp.

If the error voltage applied to resistor R94 is between V_{max} and V_{min}, set by respective voltage dividers 241, 242 (which include resistors R90/R91 and R92/R93, respectively), then both op amps 243, 244 operate in open loop fashion and become saturated with an output voltage that back biases diodes D1 and D2. If the error voltage increases above V_{max}, then the upper op amp's 243 output will be driven low enough to forward bias diode D1 through resistor R94 and close the feedback loop, creating a non-inverting unity gain amplifier. The inverting and non-inverting inputs of this op amp 243 would then be at the same potential, which is V_{max}. Any additional voltage provided from the error voltage would be dropped across resistor R94. If the error voltage were to decrease below V_{min}, then the lower op amp's 244 output will be driven high enough to forward bias diode D2 and close the feedback loop, again creating a non-inverting unity gain

amplifier. The output of the amplifier would be V_{min}, and any additional voltage provided from the error voltage would be dropped across resistor R94, as well. I prefer to use 4.7KΩ resistors at R90 and R92; 10KΩ resistors at R91 and R93; a 100KΩ resistor at R94; LM324 units in the op amps 243, 244; 1N914 diodes at D1 and D2; and a 1000pF capacitor at C4.

Phase Modulator

The preferred arrangement of the phase modulator of the invention shown in FIG. 15 includes a comparator, a one-shot, and an optocoupler U14. The phase modulation control voltage is preferably compared to the ramp voltage to produce a high-to-low logic transition when the ramp voltage exceeds the control voltage and a low-to-high transition when the control voltage exceeds the ramp voltage. The falling edge of this waveform triggers a one-shot to produce a 200 μsec pulse used to initiate conduction of the power stage. The pulse is isolated from the load by an optocoupled triac driver. The switch can be used to turn the triac on continuously in the bypass mode or to inhibit the triac in the off mode. *POR is used to momentarily inhibit triggering of the power stage after power up. FIG. 19 shows the timing for these waveforms.

The error signal is preferably compared to the ramp voltage by comparator U10 and initiates a high-to-low transition at its output when the ramp voltage is greater than the error voltage. This transition momentarily couples what is substantially ground (a true ground is nearly impossible to achieve here, so there is a small, negligibly residual voltage) across capacitor C5 that removes base drive from transistor Q17, turning it off. The off state of transistor Q17 allows transistor Q18 to regain its base drive and turn on conducting the optocoupler's LED bias current, which in turn drives the optotriac into conduction. The current supplied from the optotriac is used to trigger the power triac. When capacitor C5 reaches a preferred voltage of about 0.7 V by charging through resistor R95, transistor Q17 begins to conduct again and removes base drive from transistor Q18, turning it off. The LED bias current is removed and the optotriac output current is removed from the power triac. At the end of a predetermined ramp voltage cycle, preferably 8.33 msec, the ramp voltage is reset to ground and the comparator's output transitions from low-to-high pulled up through resistor R89. The timing capacitor C5 couples the 5 V pull-up voltage across itself and discharges through transistor Q17's base/emitter junction and resistor R89. Since resistor R89 is less than resistor R95, the discharge time constant is a

fraction of the charge time constant, which guarantees a return to a stable start condition.

The controller can be bypassed and the lamp turned on fully by applying ground to the base of transistor Q17. Switch S2 provides this function, which removes base drive from transistor Q17, turning it off continuously. With transistor Q17 off, transistor Q18 will be on, which enables continuous LED and optotriac current and, hence, the power triac will be conducting continuously. Continuous conduction will apply full voltage to the lamp, and lamp voltage must be kept below a predetermined level in this mode to avoid lamp failure and to enhance safety.

Lamps can be turned off by applying ground to the output of the comparator, which inhibits the discharging of capacitor C5 and keeps transistor Q17 conducting continuously. This state will turn the power triac off until the ground is removed as explained above.

I prefer to use 10KΩ resistors at R89and R96, a 47KΩ resistor at R95, and a 220Ω resistor at R97. I also prefer to use a LM339 comparator, a 0.01μF capacitor at C5, 2N2222 transistors at Q17 and Q18, and a MOC3021 optocoupler at U14.

Power Stage

The power stage includes a RC snubber circuit (resistor R98, resistor R99, and capacitor C6, preferably of 180Ω, 680Ω, and 0.068μF, respectively) and a triac (Q25) as shown in FIG. 16. The triac is used to switch the hot side of the AC load and is applied to the lamp ballast. The snubber reduces stress on the triac and output of the optocoupler.

Alarms

Each alarm control circuit 250 monitors the control voltage necessary to produce the desired UV intensity from the lamp it is controlling. Two active low signals are produced and used to drive three front panel indicating lamps. These lamps signal green for normal operation, yellow if the control voltage is near the end of its operating range, and red if the control is beyond its operating range. Each of the active low signals are combined with others of their kind from the rest of the control circuits to provide two separate digital discretes 450 to indicate controller status to the PLC. Each discrete 450 is preferably made available as

an uncommitted, optocoupled transistor output located on the Timing and Alarm Board in the alarms circuit 45.

The first discrete 450, called *Alarm, indicates whether any control circuit is failing to control its lamp's intensity as would happen if the lamp 3 burned out or was unable to produce the required intensity set by the PLC. The second discrete 450, called *Warning, indicates if any control circuit is near the end of its controllable range as would happen if a lamp were near the end of its usable life. Both are powered from the 5 V power supply such that a failure of the power supply will look like two alarm conditions to the PLC.

An option is available on the control board to disable an individual control circuit's contribution to the alarm or warning discretes but still indicate the state of the control signal at the front panel by the LEDs. This optional control is preferably located in the alarm control circuit area represented by the control board alarm circuit 25 shown in FIG. 7, an exemplary control circuit of which is shown in FIG. 18.

FIG. 17 shows the preferred topology used for both logic discretes 450. Resistor R31 provides base drive for transistor Q4 enabling bias current for the LED 451 of optocoupler U6 to flow under non-alarm conditions. With the LED bias current flowing, the optocoupler output transistor 452 can conduct current supplied from the PLC input logic device. When *Warn (*Alarm) goes low, the base drive is removed from transistor Q4 and the LED bias current is removed. The optocoupler's output transistor 452 will no longer conduct any current and can hold off up to 70 volts from the PLC logic input device. I prefer to use resistors of 330Ω and 10KΩ at R30 and R31, respectively; a 2N2222 transistor at Q4; and a CNY 17-1 optocoupled transistor at U6.

Each alarm control circuit 250 preferably has a window comparator 251 that compares the phase modulator control voltage to V_{max} and V_{min} as shown in FIG. 18. If the control voltage is less than V_{max}, pin 14 of comparator U3 will be pulled high through resistor R12; or if the control voltage is greater than V_{min}, pin 13 of comparator U3 will be pulled high through resistor R9. This voltage is applied to the red LED drive circuit 252 (which includes resistor R1, resistor R5, transistor Q1, and L1) and the green LED drive circuit 253 (which includes resistor R4, resistor R3, resistor R2, and transistors Q2 and Q4). The voltage applied to the red and green LED drive circuits 252, 253 turns the red LED off and the green LED on, indicating a normal operating condition for this control

circuit. The signal is also applied to the open collector nand gate U1, along with *Disable, an active low discrete. Whenever *Disable is active, the output of open collector nand gate U1 pin 3 (*fault) will be open collector regardless of the state of the other signal; but when *Disable is inactive, the output will be low when this signal is high or high when this signal is low.

If the control voltage is greater than V_{max}, the output at pin 14 of comparator U3 will be at a logic level low and pin 3 of comparator U2 will be at a logic level high, which drives the red LED on and the green LED off indicating an alarm condition. The same would be true if the control voltage were less than V_{min}, since pin 13 of comparator U3 would be low.

Similar operation occurs for the comparison of the control voltage to the signal developed by the voltage divider R21/R22. This voltage is set 10% higher than V_{min} and drives pin 2 of comparator U3 to a logic level high if the control voltage drops below this value. Under this condition, a yellow warning LED is turned on driven from transistor Q3 and resistor R6 and *Warn is pulled low.

I prefer to use 270 Ω resistors at R1, R2, and R6; 10KΩ resistors at R3 R8, R9, R12, R15, and R22, with R22 being a variable resistor; 6.8KΩ resistors at R4 and R5; and a 4.7KΩ resistor at R2. I also prefer to use 0.1μF capacitors at C1 and C2; 74L503 and 74L500 units at U1 and U2, respectively; LM339 transistors at the U3 stations; and 2N2222 comparators at Q1, Q2, Q3, and Q4.

Since the regulator is a "cut only" controller, the lamp can only be regulated to an intensity below that which it could go to if it was driven off the line by the standard ballast scheme. To allow regulation at the normal operating point, the system takes advantage of the relationship between increased intensity and increased voltages. For example, the AC primary voltage is stepped up to 140 VRMS so that a lamp that normally operates at 10 mW/cm^2 at a line voltage of 120 VRMS would produce 12 mW/cm^2 at a line voltage of 140 VRMS. The controller can now reduce the current into the lamp to restore the intensity down to the 10 mW/cm^2 level and have enough overhead to compensate for a 2 mW/cm^2 reduction in intensity due the aging of the lamp. If the same lamp operating on the controller had been set at 6 mW/cm^2, there would be enough overhead to compensate for a 6 mW/cm^2 reduction in intensity due the aging of the lamp. This additional margin translates to increased life for the lamp as compared with the 10 mW/cm^2 intensity level and illustrates the trade off that must be made in lamp life and intensity. However, even with this restriction, a

typical process could expect the controller to regulate at an operating specification over a very wide range of temperature, voltage, component variability, and lamp age.

In two exemplary contact lens casting machine embodiments, one of which includes 44 lamps, the other of which includes 20 lamps, the costs associated with having a light sensor and controller for each lamp, in addition to the space requirements, might be prohibitive to some users. I therefore allow for the use of one light sensor and controller for each of a bank of lamps. The exact number of lamps in each bank is unimportant so long as the light sensor can properly sense the light applied by the lamps.

As mentioned above, a typical cure process can comprise a main table and post cure table time and, for some systems, post cure table temperature. Other processes may employ a conveyor belt to transport the lenses and molds through a curing zone. In any case, the method according to the present invention comprises curing contact lenses in their molds by actively controlling exposure of an uncured mixture to electromagnetic radiation of specified wavelength and intensity over a particular period of time (which period of time may be the whole or any part of the overall curing time), thereby forming a desired contact lens into a predesigned shape and with preselected properties. Suitably, the intensity of radiation is within 3500 μW to 7000 μW for a period of time ranging from 3 minutes to 90 minutes, preferably 5 minutes to 45 minutes, more preferably about 10 minutes to about 30 minutes. Suitably, the intensity of radiation can be controlled by a closed loop system, one such embodiment of a closed loop system having been described above. Suitably, the variation of intensity from the desired light intensity over said time period is maintained within a range of +/- 1000 μW, preferably with a range of +/- 300 μW, more preferably within a range of +/- 40 μW over said time period. Although the intensity may be maintained constant in some cases, it may be advantageous to vary the desired light intensity over said time period. This may depend not only on the intensity of the lamp per se, but on the number of lamps in a given space and the relative position of the lamps and molds. Preferably, however, the light intensity emitted from the lamps are set at three or more different light intensities (the intensity of a lamp can be measured, for example, using a standard radiometer) and the intensity at the material being cured can be correlated. For example, the same type of lamp can have three or more intensities or three different types of lamps

having different intensities can be employed. In one possible embodiment, the desired light intensity over said time period can increase continuously over said time period linearly or non-linearly. Alternatively, the desired light intensity can be made to ramp up or ramp down over said time period, for example, in a main table cure or in a post cure. One preferred embodiment is to ramp the intensity up, then down in both a main cure and post cure. In the index casting system of FIG. 7A, for example, the light source for each index, which typically lasts 30 seconds, can be individually controlled, the series of indexes, for example, increasing in a stair-step manner.

It has been found, for example, that preselected properties of silicon hydrogel lenses (PUREVISION made by Bausch & Lomb, Inc. in Rochester, NY) benefit from a relatively slow first stage cure. Without wishing to be bound by theory, it is surmised that this may be due to optimal polymerization not occurring if there are too many radicals too soon, resulting in the polymer not building as well. As a consequence, a relatively slow front cure on the main table, in contrast to a relatively fast front cure, has been found to provide better consistency and to improve (reduce) extractables. In the case of the PUREVISION lenses, an improved collection of properties, including water content, diameter, and sag, has all been correlated together using a relatively slow front cure. However, the optimal path of cure for a given lens will depend on the identity of the monomers or other ingredients being reacted during cure.

In general, the desired light intensity profile over time, the so-called path of cure, can be determined or optimized for a given lens material or mold system by testing various profiles and selecting the profile that produces the best results in terms of lens properties. The profiles can be determined by experimental design employing, for example, a multiple response optimization algorithm, through manipulation of the intensities controlled by the light-source controller and examination of the properties of the lens after cure. Once the optimum profile is established, the controllers are programmed to deliver the exact dose at the right time.

For example, for a particular lens material or curing system, the path of cure (based on the intensity profile of the actinic radiation to which the lens is exposed over time) can be varied to find the path that results in the optimal or most consistent properties or combinations of properties, including lens diameter, sag, center thickness, water content, extractable levels, tear,

and/or modulus. For example, a casting process equipped with UV lamps and controllers could be used to establish an intensity profile that optimizes the cure by delivering a precise and timely radiation dose(s) to a monomer system as it cures.

I Claim:

1. A method of curing a contact lens in a mold comprising closed loop control of the variation and/or change in intensity over time of the electromagnetic radiation used to cure the lens-material precursor, thereby forming a contact lens into a predesigned shape with preselected properties.

2. The method of claim 1, wherein the intensity of radiation substantially at the lamp is within 3500 $\mu W/cm^2$ to 7000 $\mu W/cm^2$ for a period of time ranging from 5 minutes to 90 minutes, preferably about 10 minutes to about 45 minutes.

3. The method of claim 2 wherein the intensity of radiation substantially at the lamp is controlled by a closed loop system and wherein the variation of intensity from the desired light intensity over said time period is maintained within a range of 1000 $\mu W/cm^2$, preferably with a range of 300 $\mu W/cm^2$, more preferably within a range of 40 $\mu W/cm^2$ over said time period.

4. The method of claim 1 wherein the desired light intensity is produced by a plurality of the same or different lamps, wherein at least three different light intensities are emitted by the lamps.

5. The method of claim 1 wherein the desired light intensity over said time period increases continuously or in ramp fashion over time.

6. The method of claim 1 wherein the desired light intensity over said time period ramps up over time or ramps down over time or both.

7. The method of claim 1 wherein exposure is actively controlled by determining an actual intensity emitted by a source of the particular wavelength of electromagnetic radiation and controlling power applied to the source of the particular wavelengths of electromagnetic radiation.

8. The method of claim 7 wherein the actual intensity is determined by sensing the actual intensity of the particular wavelengths of electromagnetic radiation.

9. The method of claim 7 wherein the particular wavelength is a first wavelength and an actual intensity of the first wavelength is determined by sensing an actual intensity second wavelength emitted by the source, generating a signal representative of the actual intensity of the second wavelength, and converting the actual intensity of the second wavelength to the actual intensity of the first wavelength in accordance with a particular relationship between the first and second wavelengths emitted by the source.

10. The method of claim 7 wherein the particular wavelength is a first wavelength, the particular intensity is a desired intensity of the first wavelength, and exposure is actively controlled by generating a signal representing the desired first wavelength intensity, sensing and generating a signal representative of an actual intensity of a second wavelength of electromagnetic radiation emitted by the source, converting the desired first wavelength intensity signal to a signal representing a desired intensity of the second wavelength, and generating a control signal by combining the desired and actual second wavelength intensity signals.

11. The method of claim 10 wherein exposure is further actively controlled by applying the control signal to a power stage of the source, thereby controlling electrical current flowing through the source and intensity of electromagnetic radiation proportional thereto.

12. The method of claim 1 wherein exposure takes place in a curing machine using a fluorescent lamp.

13. The method of claim 12 wherein the curing machine is an index casting machine including a plurality of clamping positions to which molds can be attached, a plurality of lamps, and a plurality of index positions to which each clamping position can be moved and stopped for a predetermined period.

14. The system of claim 13 wherein the curing machine is a post cure table.

15. A polymer curing and contact lens manufacturing system including:

a casting machine in which cure of uncured contact lenses begins, the uncured contact lenses including a component responsive to a particular wavelength of electromagnetic radiation;

a plurality of fluorescent lamps mounted in the casting machine, the lamps acting as a source of the particular wavelength of electromagnetic radiation; and

a closed loop controller actively controlling output intensity of at least one of the lamps and including:

a sensor that senses a first intensity of a first wavelength of electromagnetic radiation emitted by the at least one lamp in a first wavelength range to produce a first intensity signal;

a determiner that determines a desired intensity of a second wavelength of electromagnetic radiation emitted by the at least one lamp in a second wavelength range;

a desired intensity signal generator that generates a desired intensity signal based on a relationship between the first and second wavelengths of electromagnetic radiation emitted by the at least one lamp and the desired intensity of the second wavelength of electromagnetic radiation; and

a lamp current control signal generator that generates a lamp current control signal based on the first intensity signal and the desired intensity signal, the lamp current control signal causing current to be applied to the at least one lamp at a level that will produce a desired intensity of the second wavelength, thereby maintaining the desired intensity of the second wavelength of electromagnetic radiation emitted by the at least one lamp.

16. The system of claim 15 wherein the first wavelength is a visible wavelength of light and the first wavelength range falls at least partially within the visible spectrum of light.

17. The system of claim 15 wherein the second wavelength is an ultraviolet wavelength and the second wavelength range falls at least partially within the ultraviolet spectrum of light.

18. The system of claim 15 wherein the step of sensing includes providing a photodiode responsive to the first wavelength, the photodiode generating the first intensity signal when it is exposed to electromagnetic radiation emitted by the lamp at the first wavelength.

19. The system of claim 15 wherein the step of sensing includes conditioning the first intensity signal.

20. The system of claim 15 wherein the steps of determining a desired intensity and generating a desired intensity signal include providing a programmable electronic controller that includes a memory in which the relationship between the first and second wavelengths is stored, a processor that determines a strength of the desired intensity signal based on the first intensity signal and the relationship, and a desired intensity signal generator that generates the desired intensity signal at the determined strength.

21. The system of claim 15 wherein the step of generating a lamp current control signal includes combining the first and desired intensity signals, sending a result of the combining to a phase modulator that controls a triac drive, and adjusting current applied to the lamp with the triac drive so that the lamp produces the desired intensity of the second wavelength.

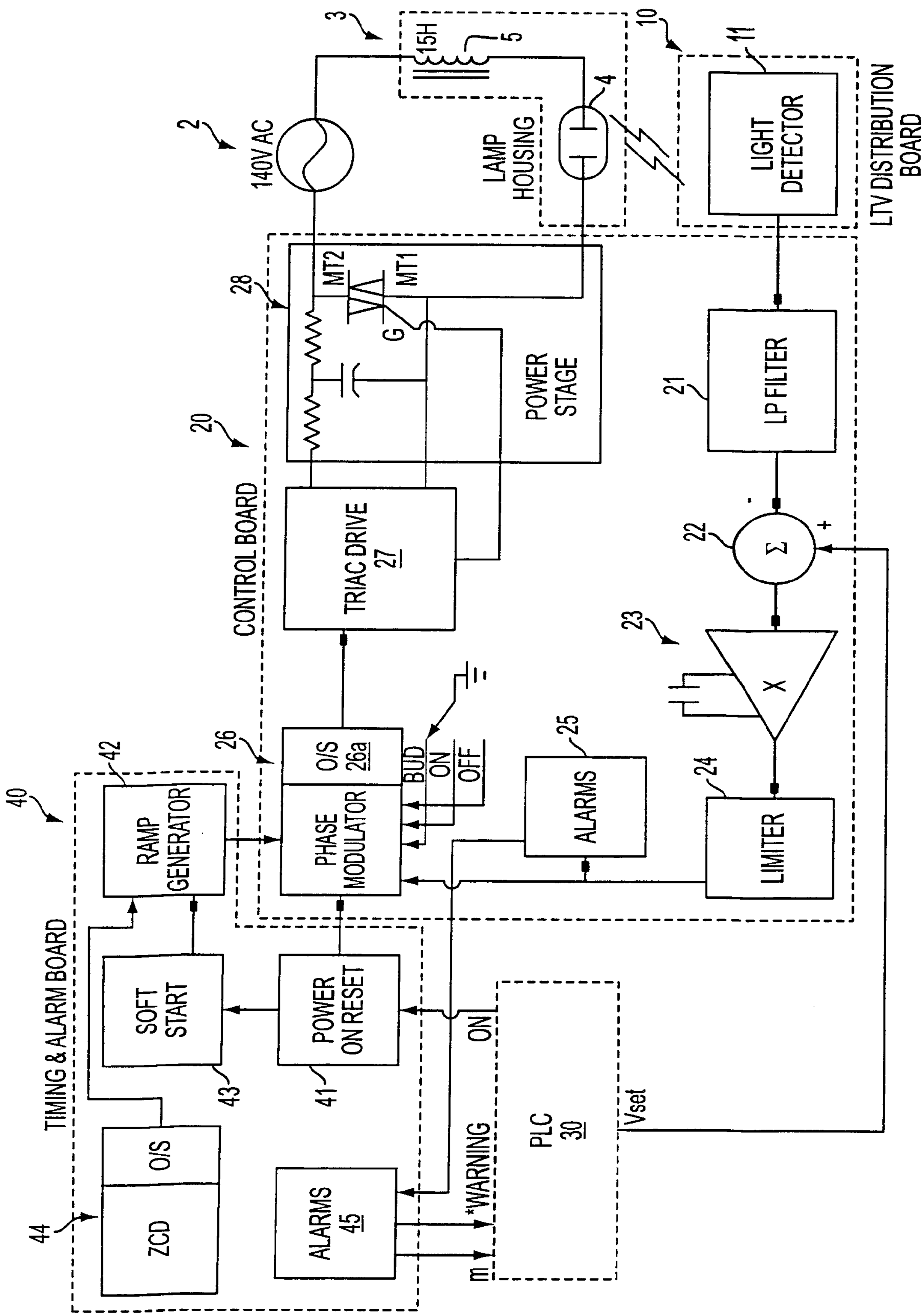
2
140V AC
3
15H
5
LAMP HOUSING
4
10
11
LIGHT DETECTOR
LTV DISTRIBUTION BOARD
28
MT2
MT1
G
POWER STAGE
20
CONTROL BOARD
21
LP FILTER
22
Σ
-
+
TRIAC DRIVE 27
23
X
26
O/S 26a
BUD
ON
OFF
25
ALARMS
24
LIMITER
40
42
RAMP GENERATOR
PHASE MODULATOR
TIMING & ALARM BOARD
SOFT START
POWER ON RESET
43
41
ON
Vset
PLC 30
*WARNING
44
O/S
ZCD
ALARMS 45
m

FIG. 7B

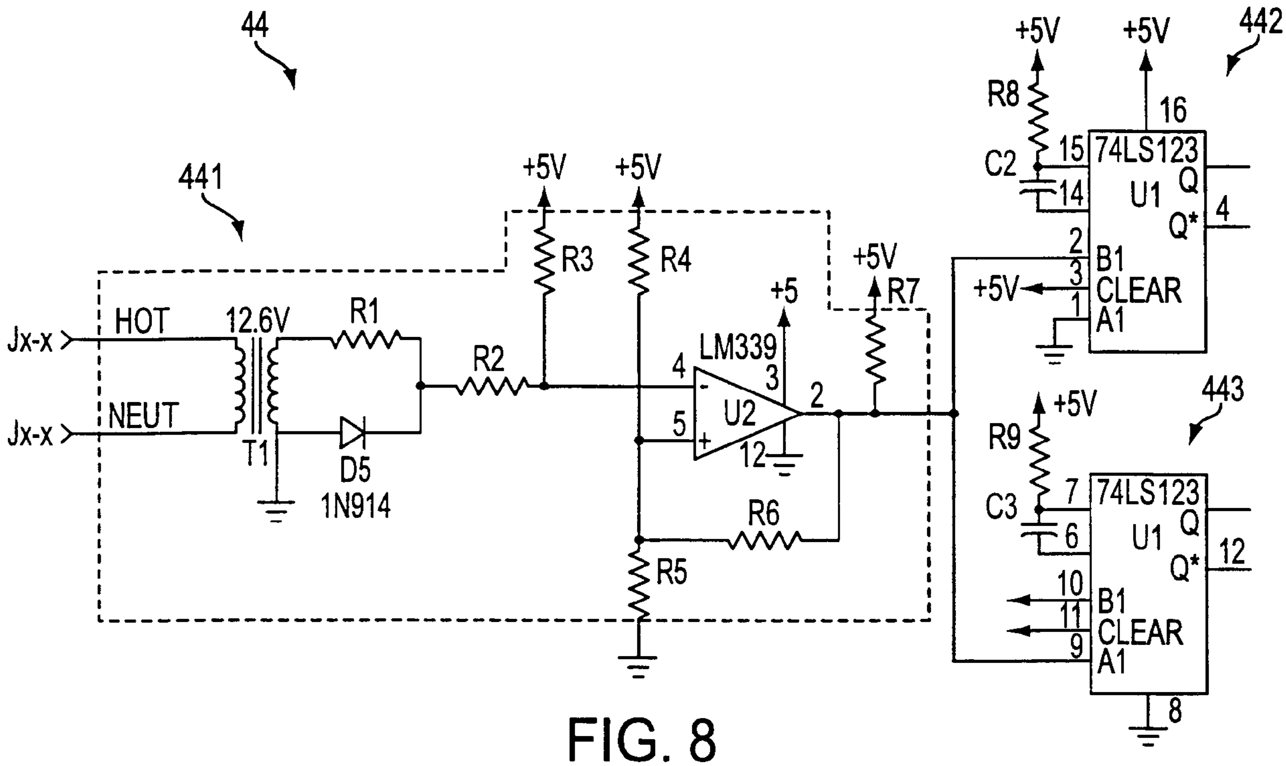
44
441
442
443
Jx-x
HOT
Jx-x
NEUT
12.6V
T1
R1
D5
1N914
R2
+5V
R3
+5V
R4
LM339
+5
U2
4
5
3
2
12
R5
R6
+5V
R7
+5V
R8
C2
16
15
14
74LS123
U1
Q
Q*
4
2
B1
3
CLEAR
+5V
1
A1
+5V
R9
C3
7
6
74LS123
U1
Q
Q*
12
10
B1
11
CLEAR
9
A1
8

FIG. 8

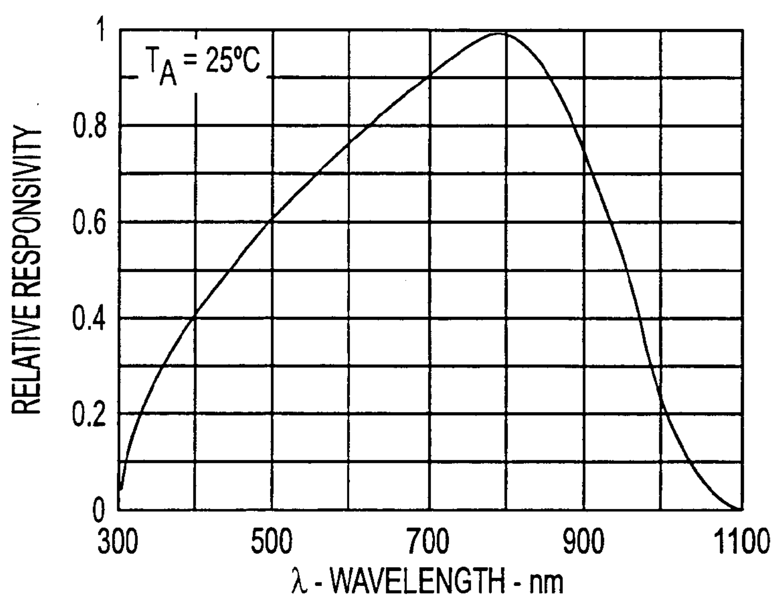
T_A = 25ºC
RELATIVE RESPONSIVITY
1
0.8
0.6
0.4
0.2
0
300
500
700
900
1100
λ - WAVELENGTH - nm

FIG. 12

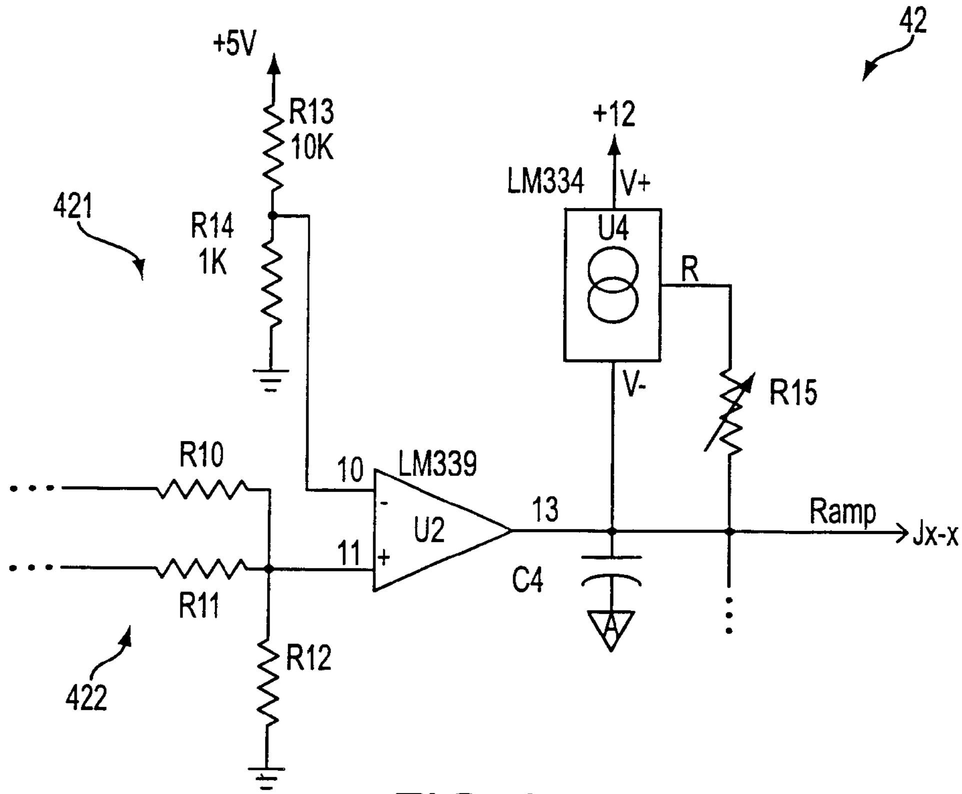
42
+5V
R13
10K
421
R14
1K
+12
LM334
V+
U4
R
V-
R15
R10
10
LM339
-
U2
13
Ramp
Jx-x
11
+
R11
C4
R12
422

FIG. 9

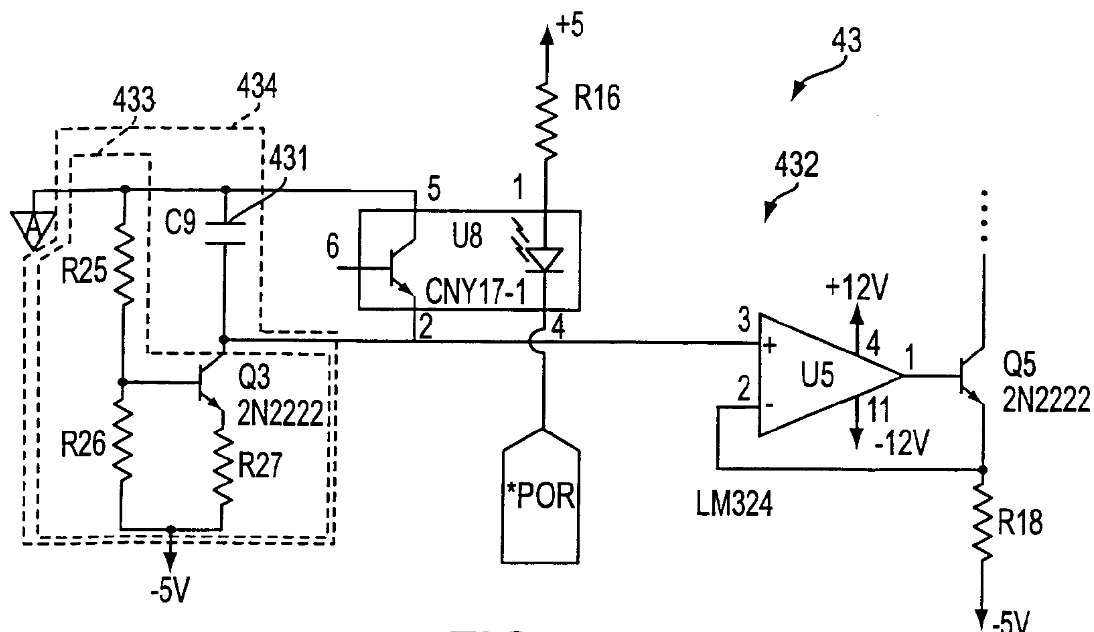
+5
R16
43
433
434
431
432
5
1
C9
U8
6
R25
CNY17-1
+12V
3
2
4
+
4
1
Q3
2N2222
U5
Q5
2N2222
2
-
11
R26
R27
-12V
*POR
LM324
R18
-5V
-5V

FIG. 10

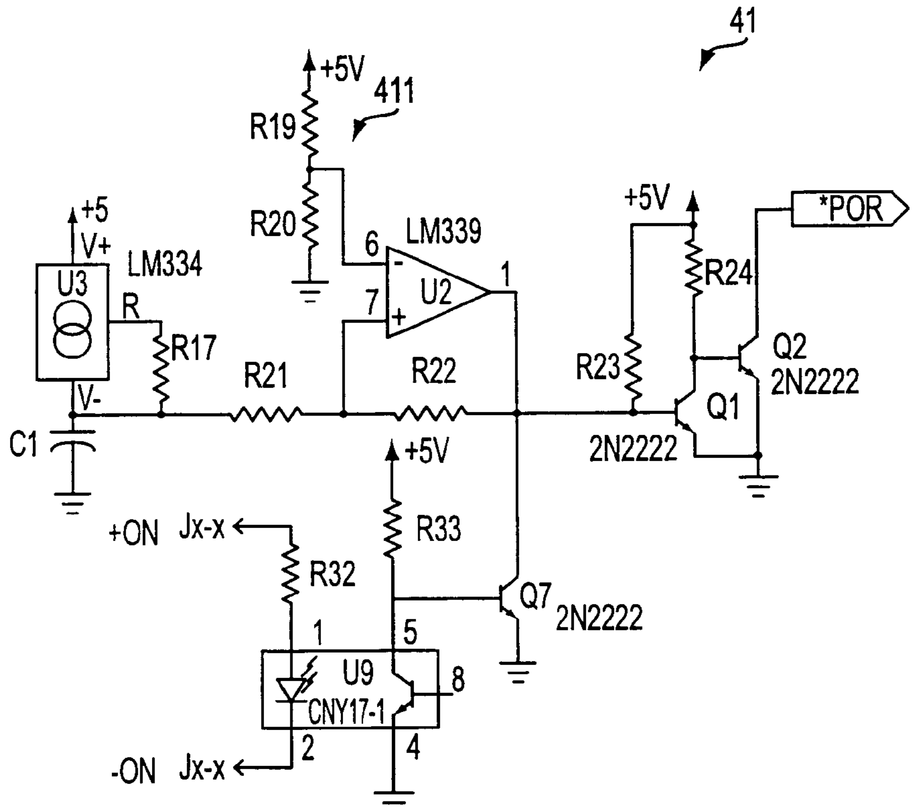
41
411
+5V
R19
R20
6
LM339
U2
1
7
+5
V+
LM334
U3
R
R17
R21
R22
V-
C1
+5V
R24
*POR
R23
Q2
2N2222
Q1
2N2222
+5V
R33
+ON Jx-x
R32
Q7
2N2222
1
5
U9
CNY17-1
8
2
4
-ON Jx-x

FIG. 11

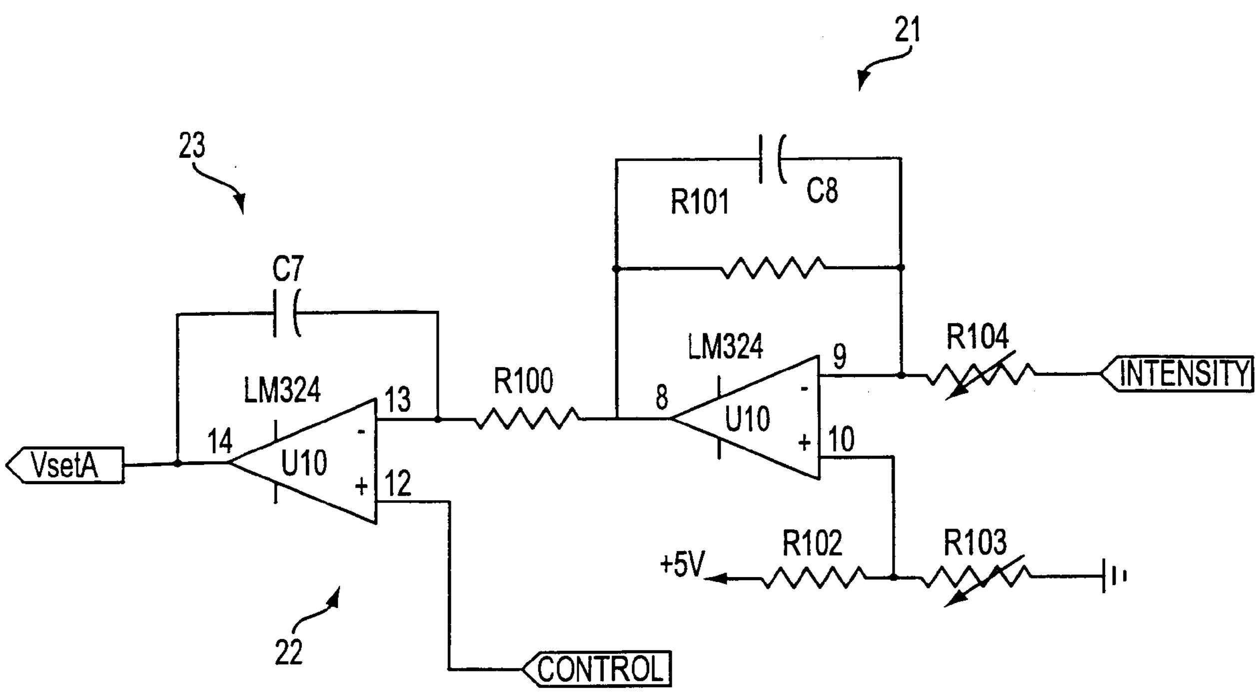
21
23
R101
C8
C7
LM324
9
R104
INTENSITY
LM324
13
R100
8
U10
14
U10
10
VsetA
12
+5V
R102
R103
22
CONTROL

FIG. 13

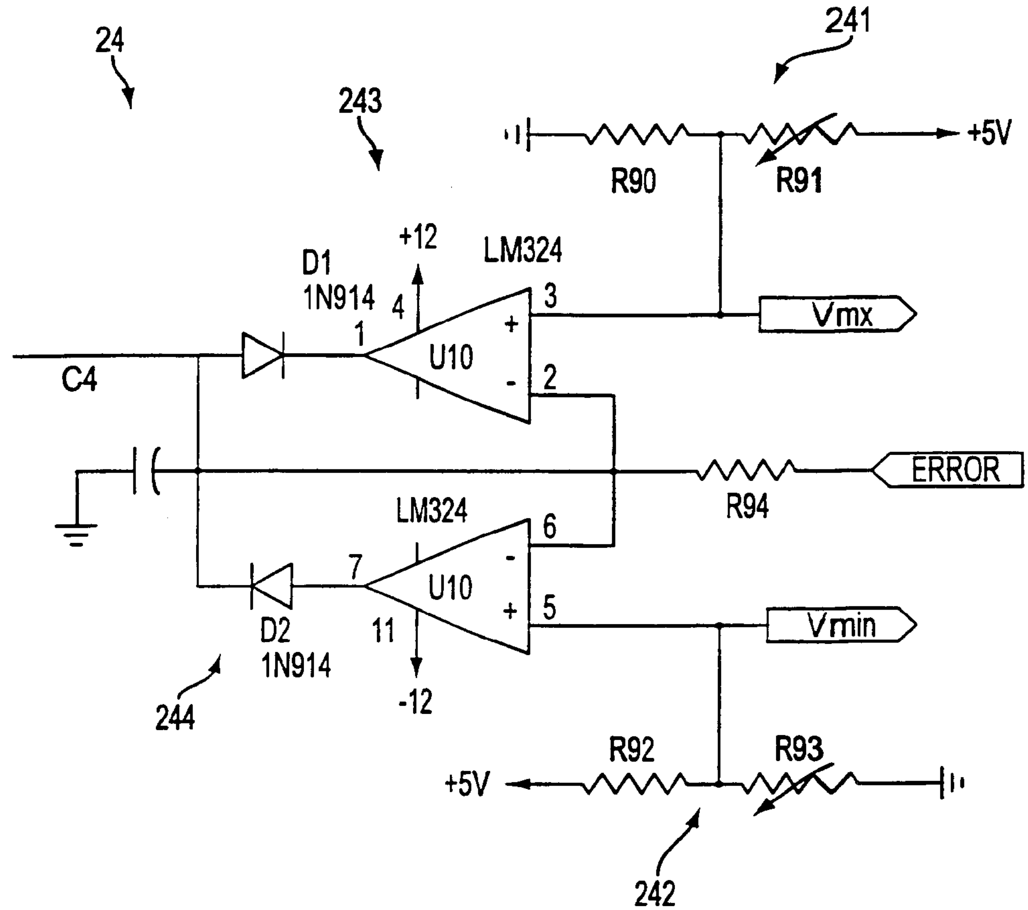
24
243
241
R90
R91
+5V
D1
1N914
+12
LM324
4
3
1
U10
+
Vmx
C4
-
2
ERROR
R94
LM324
6
7
U10
-
+
5
Vmin
D2
1N914
11
-12
244
R92
R93
+5V
242

FIG. 14

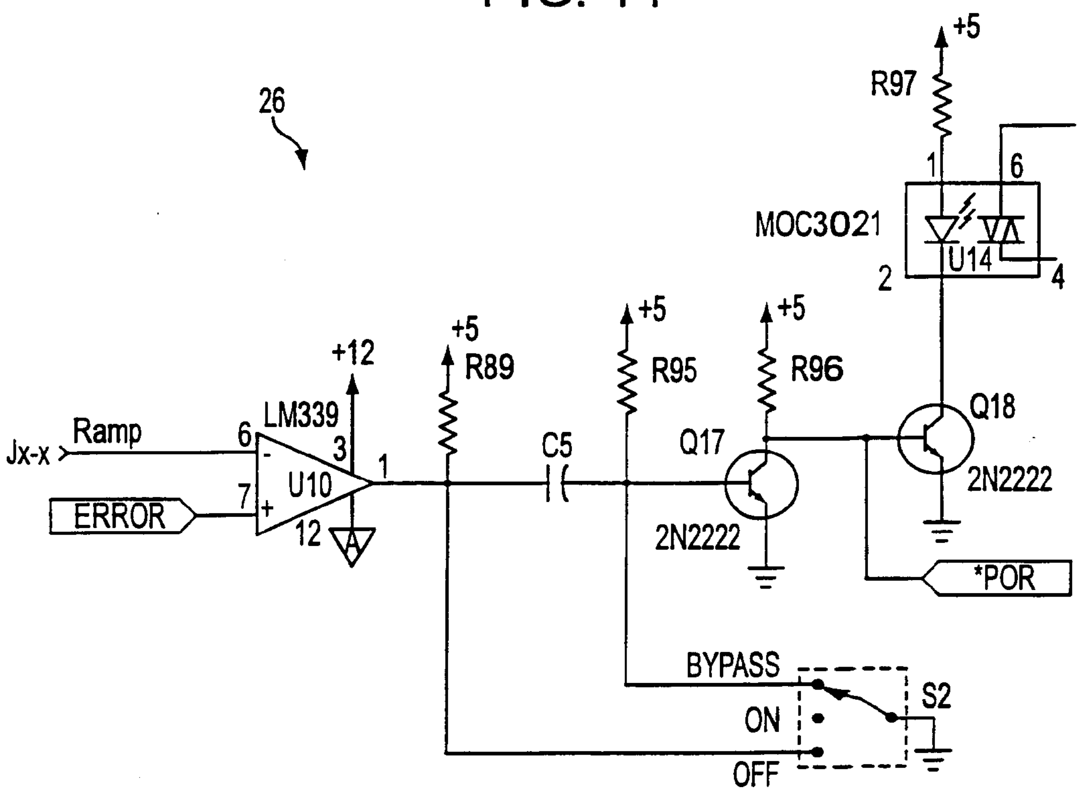
+5
R97
26
1
6
MOC3021
U14
2
4
+5
+5
+12
+5
R89
R95
R96
Q18
LM339
C5
Q17
Jx-x
Ramp
6
3
1
U10
2N2222
ERROR
7
12
2N2222
*POR
BYPASS
S2
ON
OFF

FIG. 15

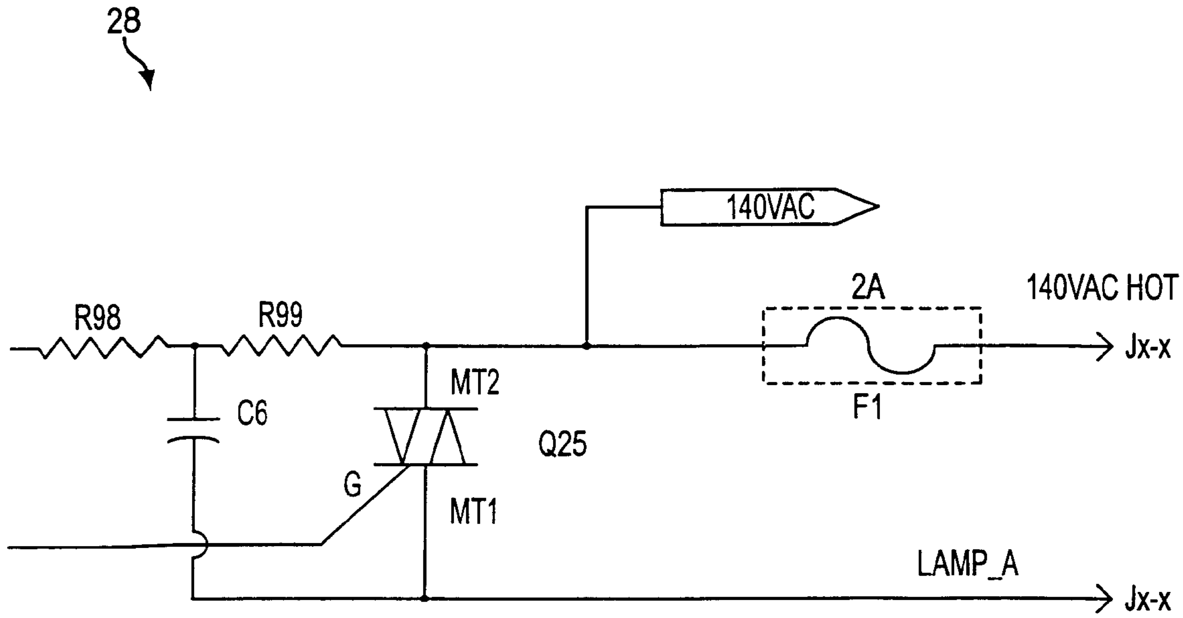
28
140VAC
R98
R99
2A
140VAC HOT
Jx-x
MT2
C6
Q25
F1
G
MT1
LAMP_A
Jx-x

FIG. 16

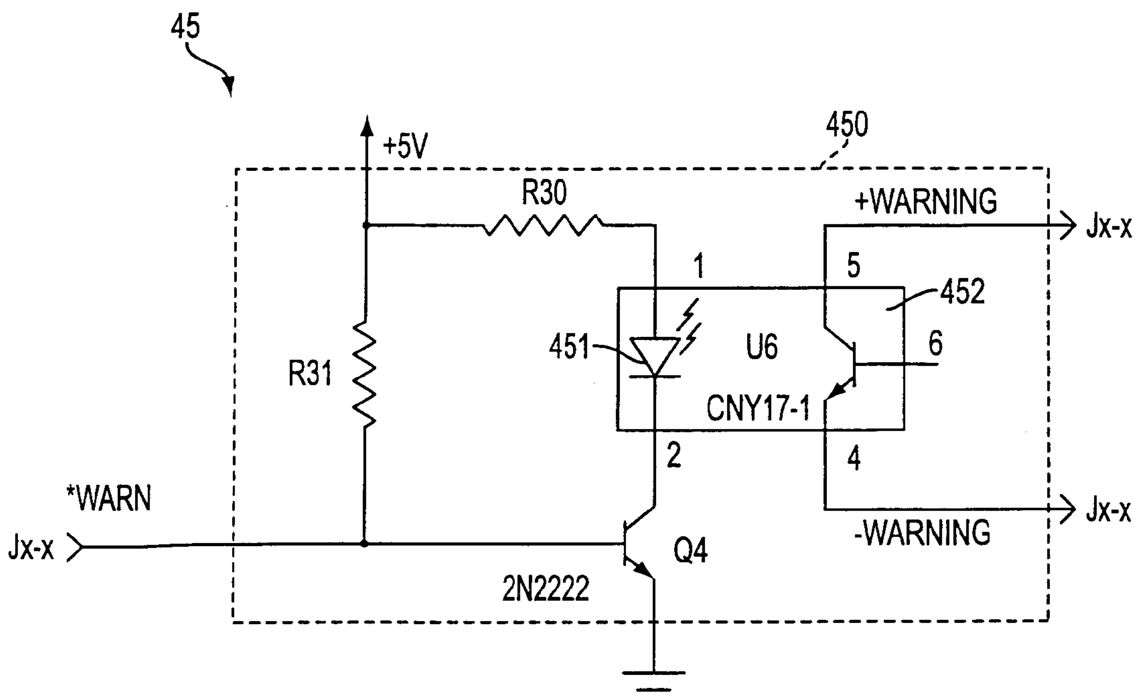
45
+5V
450
R30
+WARNING
Jx-x
1
5
452
451
U6
6
R31
CNY17-1
2
4
*WARN
Jx-x
Jx-x
-WARNING
Q4
2N2222

FIG. 17

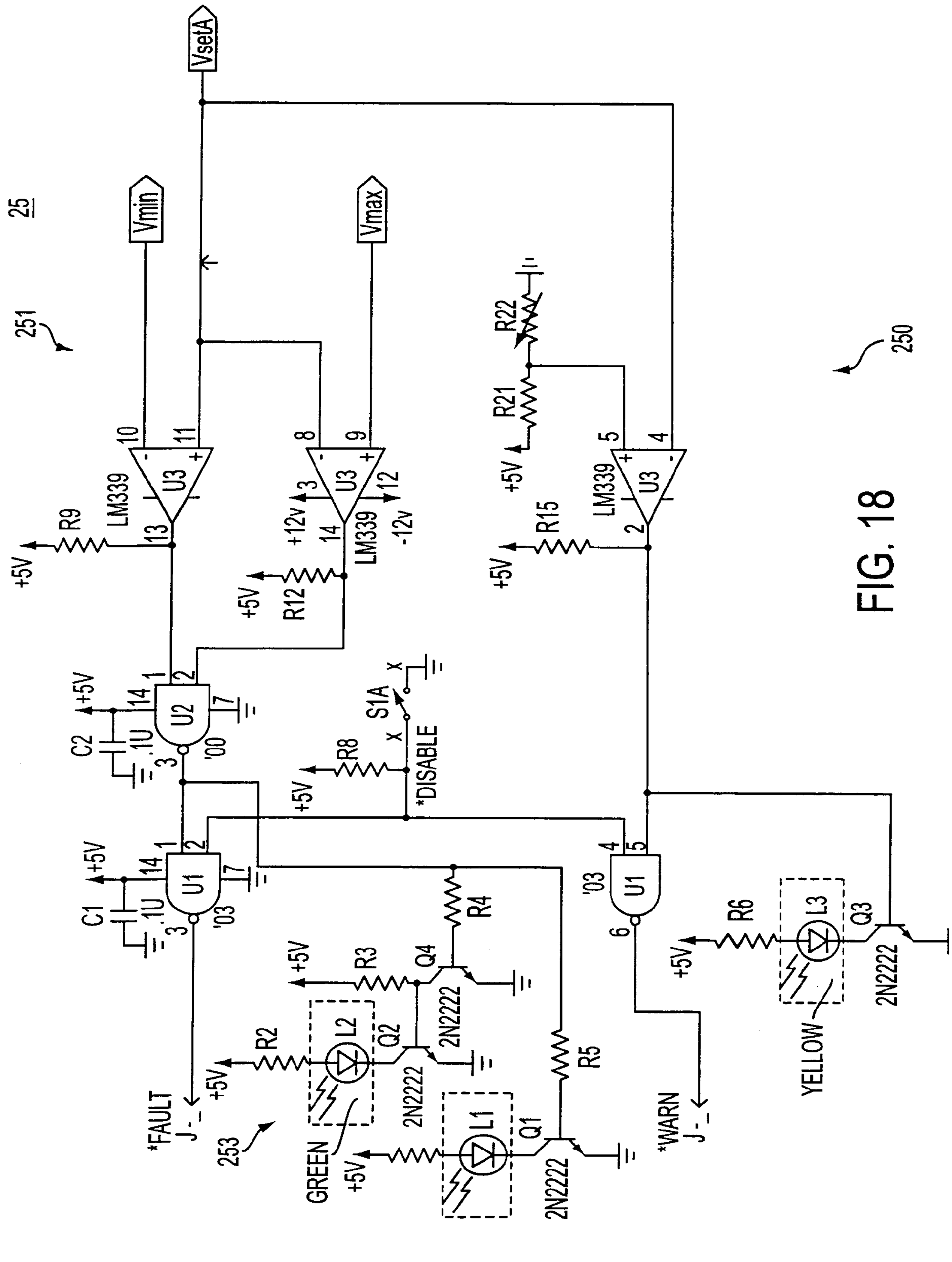
25
251
Vmin
VsetA
Vmax
R22
R21
+5V
10
11
8
9
5
4
U3
LM339
+12v
-12v
14
12
3
13
2
R9
R12
R15
U2
'00
C2
.1U
U1
'03
C1
R8
S1A
*DISABLE
R4
R3
Q4
2N2222
R2
L2
Q2
R5
L1
Q1
R6
L3
Q3
YELLOW
GREEN
*FAULT
J-_
*WARN
J-_
253
250
6
7
1

FIG. 18

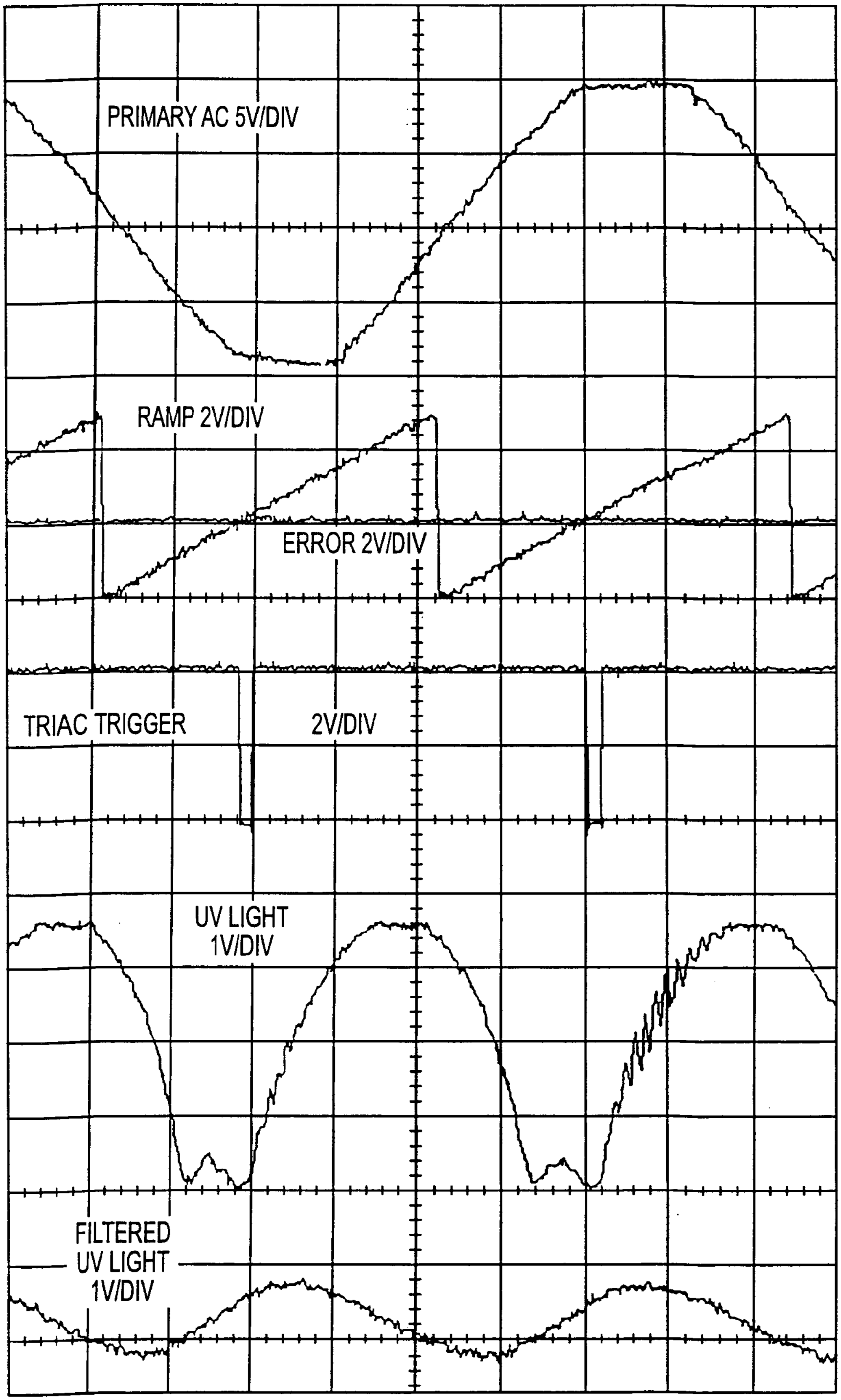
PRIMARY AC 5V/DIV
RAMP 2V/DIV
ERROR 2V/DIV
TRIAC TRIGGER
2V/DIV
UV LIGHT
1V/DIV
FILTERED
UV LIGHT
1V/DIV

FIG. 19

INTERNATIONAL SEARCH REPORT

Intern ,nal Application No
PCT/US 00/22944

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H05B41/392 B29D11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H05B B29D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99 06887 A (Q2100 INC) 11 February 1999 (1999-02-11) abstract page 19, line 19 - line 35 page 47, line 4 - line 23 figures 13,14 -----	1,4,7, 12-14

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 November 2000	04/12/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Helot, H

INTERNATIONAL SEARCH REPORT

Information on patent family members

Intern. ,nal Application No
PCT/US 00/22944

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9906887 A	11-02-1999	US 5989462 A	23-11-1999
		AU 8763698 A	22-02-1999
		EP 1000385 A	17-05-2000